

# On the CVC problem in $\tau$ -decay

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## Abstract

The preliminary results of PIBETA experiment strongly suggest the presence of non  $V - A$  anomalous interactions in the radiative pion decay. We assume that they arise as a result of the exchange of new intermediate chiral spin-1 bosons which interact anomalously with matter. Their contribution into the  $\tau$ -decay leads to violation of the CVC hypothesis at the same level as detected experimentally.

The  $\tau$  lepton weak decay into the  $\rho$  meson  $\tau^- \rightarrow \nu\rho^-$  is a pure vector process. On the other hand the  $\rho$  meson can be produced in  $e^+e^-$  annihilation through a virtual photon  $e^+e^- \rightarrow \gamma^* \rightarrow \rho^0$ . According to the Standard Model (SM) the  $W$ -boson and the photon originate from the same multiplet of  $SU_W(2)$  group and they have the same form of vector coupling with matter. Therefore, these two processes of the  $\rho$  meson production should be related by the CVC hypothesis [1].

In order to estimate hadronic contribution  $a_\mu^{\text{had}}$  into the muon anomalous magnetic moment a comprehensive analysis of  $e^+e^-$  and  $\tau$  data has been fulfilled [2]. Since the main contribution in  $a_\mu^{\text{had}}$  comes from the  $\rho$ -resonance region the  $\pi^+\pi^-$  channel has been thoroughly investigated. After taking into account all known isospin breaking corrections it was found that the  $\tau$ -data lead to a bigger value of  $a_\mu^{\text{had}}$ . The reason of that is discrepancy (up to 10%), mainly above the  $\rho$ -resonance region, in spectral functions  $v_0(s)$  and  $v_-(s)$  extracted from  $e^+e^-$  [3, 4] and  $\tau$  [5] data. Despite of larger errors this discrepancy is even more pronounced in comparison with the older  $e^+e^-$  experiments [3] data which show systematically lower values of the spectral function  $v_0(s)$  than  $v_-(s)$ .

To find solution of this problem the authors [6] have assumed that the problem is mainly due to additional isospin breaking effects and not to experimental ones. The solution suggested in this letter is more radical and is based on present experimental data. The anomalous results [7, 8] on the radiative pion decay  $\pi \rightarrow e\nu\gamma$  (RPD), which also have problem with CVC hypothesis, definitely lead to prediction of the discussed effect in the  $\tau$ -decay. In other words the destructive interference in RPD and excess of the  $\rho$  meson production in the  $\tau$ -decay are due to the presence of new *centi-weak* tensor interactions.

The idea of possible presence of such interactions is very simple and natural [9]. They could be induced by an exchange of new *chiral* spin-1 particles, which are different from the gauge ones. The introduction of an additional new type of spin-1 particles follows from the fact, that in the relativistic theory there are *two inequivalent* representations of the Lorentz group with spin 1. All known spin-1 particles, the photon,  $Z$ ,  $W$ , and the gluons, are described by the gauge fields  $A_\mu$ , which are transformed under the vector representation  $(1/2, 1/2)$ . Obviously, the antisymmetric tensor fields  $T_{\mu\nu}$  transforming under the other inequivalent representation  $(1, 0) + (0, 1)$  can describe unknown yet spin-1 particles. They just lead to effective tensor interactions.

Such type of chiral spin-1 bosons can be identified among the hadron resonances [10]. Owing to the unique quantum numbers  $1^{+-}$  ( $J^{PC}$ )  $b_1(1235)$  meson just represents a pure state of the chiral axial-vector particle interacting anomalously with the tensor quark current  $\partial_\nu(\bar{q}\sigma_{\mu\nu}\gamma^5 q)$ . It was shown also that the  $\rho(770)$  and  $\rho'(1450)$  mesons are two orthogonal states consisting of mixture of pure gauge-like and chiral vector particles with near maximal mixing. This leads to a number of predictions, namely the mass formula

$$3m_{b_1}^2 = 2m_{\rho'}^2 - m_{\rho'}m_{\rho} + 2m_{\rho}^2, \quad (1)$$

which is fairly satisfied also for the spin-1 isosinglets  $I = 0$   $\omega(782)$ ,  $\omega'(1420)$ ,  $h_1(1170)$

and  $\phi(1020)$ ,  $\phi'(1680)$ ,  $h_1(1380)$ ; the ratio

$$\frac{f_\rho^T}{f_\rho} \simeq \frac{1}{\sqrt{2}} \quad (2)$$

of the  $\rho$  meson couplings to vector and tensor currents defined as

$$\begin{aligned} \langle \rho^-(q) | \bar{d} \gamma_\mu u | 0 \rangle &= m_\rho f_\rho \varepsilon_\mu^*, \\ \langle \rho^-(q) | \bar{d} \sigma_{\mu\nu} u | 0 \rangle &= i f_\rho^T (q_\mu \varepsilon_\nu^* - q_\nu \varepsilon_\mu^*), \end{aligned} \quad (3)$$

which is in good accordance with the QCD sum rules [11] and the lattice calculations [12].

Now it is natural to assume that the same phenomenon may take place on more fundamental level. One of the possibilities to incorporate the chiral spin-1 particles into SM, has been presented in [13]. Then the effective Lagrangian of quark-lepton tensor interactions reads

$$\mathcal{L}_T = -f_T \frac{G}{\sqrt{2}} \bar{u} \sigma_{\lambda\alpha} d \frac{4q_\alpha q_\beta}{q^2} \bar{e} \sigma_{\lambda\beta} (1 - \gamma^5) \nu_e + \text{h.c.}, \quad (4)$$

where  $q_\mu$  is the momentum transfer between quark and lepton currents. The dimensionless constant  $f_T$  determines the relative strength of the new tensor interactions with respect to the ordinary weak interactions and it is predicted to be positive. Using the result of ISTRA experiment on RPD [7] and applying the QCD sum rules method with PCAC technique [14] one estimates the tensor coupling constant as  $f_T \sim 0.02$  [15].

To explain the result of high statistics and high precision PIBETA experiment [8] on RPD two times smaller value of the tensor coupling constant  $f_T \simeq 0.01$  is necessary.

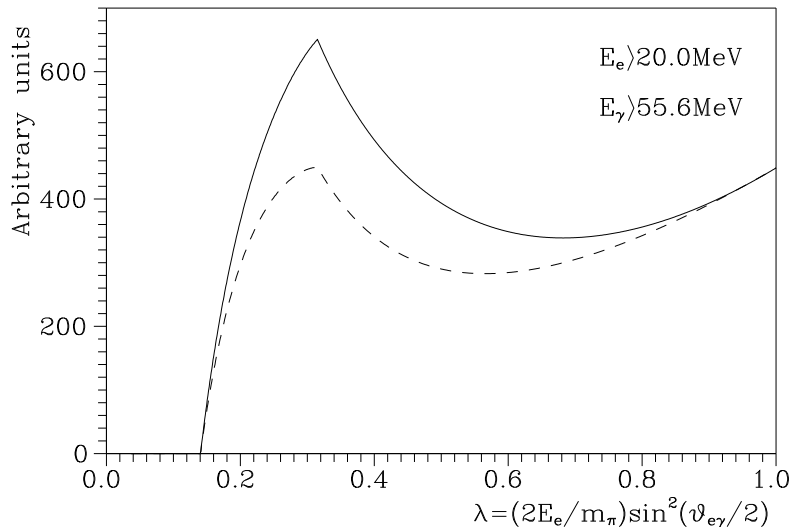


Figure 1: Theoretically predicted RPD yield is shown by the solid curve. The dashed curve presents the effect of the new tensor interactions (4) with  $f_T = 0.01$ .

In the Fig. 1 the qualitative agreement for the deficit in PRD yield with [8] is shown. In other words the new tensor interactions are two orders of magnitude weaker than ordinary weak interactions and present new class of *centi-weak* interactions.

Although the chiral fields are transformed as doublets under  $SU_W(2)$  and the gauge fields, corresponding to  $W$ -bosons, are transformed as triplets, they can mix after the symmetry breaking like the  $\rho - \rho'$  mixing in hadron physics. If the chiral bosons are very heavy then it is a unique possibility for them to manifest themselves through a mixing with  $W$ -bosons. This case was considered in [16]. It seems that the case of pure mixing, neglecting the interactions (4), is disfavored by the present data. However, a combined case may be revealed by a precise fit of PIBETA data.

To estimate an effect of the new tensor interactions on  $\tau$ -decay the Lagrangian (4) will be used. The matrix element of  $\tau$ -decay into  $\rho$  meson can be obtained using definitions (3)

$$\mathcal{M} = -\frac{G}{\sqrt{2}} m_\rho f_\rho \varepsilon_\mu^*(q) \bar{\nu}_\tau (1 + \gamma^5) \gamma_\mu \tau - 4i f_T \frac{G}{\sqrt{2}} f_\rho^T q_\mu \varepsilon_\nu^*(q) \bar{\nu}_\tau (1 + \gamma^5) \sigma_{\mu\nu} \tau. \quad (5)$$

Then the ratio of the spectral functions  $v_-(s)$  and  $v_0(s)$  at the  $\rho$ -resonance region

$$\frac{v_-(s)}{v_0(s)} = 1 + F_T \frac{6s}{m_\tau^2 + 2s} + F_T^2 \frac{s(2m_\tau^2 + s)}{m_\tau^2(m_\tau^2 + 2s)}, \quad (6)$$

where

$$F_T = 4f_T \frac{m_\tau}{m_\rho} \frac{f_\rho^T}{f_\rho} > 0, \quad (7)$$

should be greater than one even in the limit of exact isospin invariance.

Since the  $\rho$  and  $\rho'$  mesons are the mixture of gauge-like and chiral vector states the coupling constants  $f_\rho$  and  $f_\rho^T$  are not constants anymore and they depend on  $s = q^2$  in a specific way [10]. Explicit forms of these dependencies can help, probably, to specify more accurately resonance fitting parameters. For a simple evaluation of the effect of the new tensor interactions one can use the coupling constants ratio (2) at  $s = m_\rho^2$ . It leads to 5.5% excess in the  $\rho$  production in  $\tau$ -decay with respect to CVC prediction. This value is in good agreement with the ratio

$$\frac{B^{\text{exp}}(\tau^- \rightarrow \nu_\tau \pi^- \pi^0) - B^{\text{CVC}}(\tau^- \rightarrow \nu_\tau \pi^- \pi^0)}{B^{\text{CVC}}(\tau^- \rightarrow \nu_\tau \pi^- \pi^0)} = 6.2 \pm 1.4\% \quad (8)$$

derived from the older data [3] and does not contradict  $3.8 \pm 1.4\%$  when the new data [4] are used.

Therefore, the introduction of the new tensor interactions (4) allows to explain both the significant deficit in RPD yield and the excess of the  $\rho$  mesons in  $\tau$ -decay with respect to CVC predictions. These effects are noteworthy now because they are statistically significant and based on several experiments and many experimental data.

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